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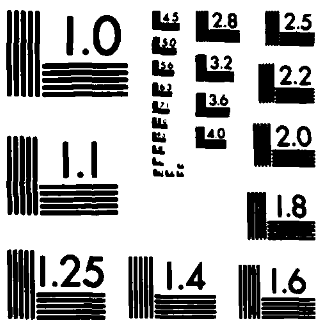

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OVERVIEW: TECHNIQUES FOR THE ANALYSIS OF SPECTRAL AND ORBITAL CONGESTION IN SPACE SYSTEMS

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OVERVIEW: TECHNIQUES FOR THE ANALYSIS OF SPECTRAL AND ORBITAL CONGESTION IN SPACE SYSTEMS[1]

ABSTRACT

Future growth in commercial and military space systems is constrained by technical problems associated with the frequency spectrum, by orbital congestion, and by costs stemming from proliferated terminals. The authors outline an Air Force sponsored research project to design and develop a capability for predicting and analyzing the spectrum/orbital geometry requirements of current projected U.S. and international space-related systems. The two essential components of the project are a comprehensive space environment data base and a computer analysis program. In combination, they will provide a resource for evaluating engineering and architectural designs, identifying and analyzing the impact of intentional and unintentional electromaguetic interference, and predicting probable saturation conditions in spectrum usage and satellite/orbital positions. The projected capabilities could provide an essential national resource for management decisionmaking and architectural planning on space-related programs. The U.S. Air Force Space Division is establishing a continuing project to utilize these capabilities.

I. INTRODUCTION

The United States Air Force has a leadership role in the development and operation of space systems for the Department of Defense. Planning for future space-related programs must account for

[1]This paper was prepared for presentation at the October 21-24, 1984, IEEE Military Communications Conference, Los Angeles, California, in a special session on Orbit/Spectral Congestion and Vulnerability Analysis of Space Systems. The presentations included in this session and noted in this paper were selected from topics discussed in the referenced Rand report.

anticipated growth in the number of space systems, which will include ground networks, large multifunction satellites, increased data transmission rates, and effects on future requirements for spectrum allocations and orbital positions.

Projected advances in the use of space by the military and other organizations for communications, navigation, surveillance, space transportation systems, and other missions, coupled with increased launch rates by U.S. military, intelligence, and commercial interests and by international agencies, will add substantially to the data link traffic and data processing requirements in earth-to-satellite, satellite-to-satellite, and satellite-to-earth communications and relay systems.

There also has been a steady increase in the number of objects in orbit, including active and inactive satellites and space debris. The probability of collision of spacecraft and debris will increase as the number of space objects, sizes of spacecraft, and on-orbit lifetimes grow. These expansions of signal transmissions and orbiting objects could severely affect the frequency spectrum allocations, orbit assignments, and related earth segments of space systems. Available spectrum, and the useful orbital positions as defined by today's capabilities, may be inadequate, leading to the condition we refer to as spectral and orbital congestion. Positional changes that may be required to avoid collisions may lead to radio frequency spectrum interference with other satellites. The analysis process and capabilities described in this paper should provide a resource for evaluating engineering and architectural designs, predicting and analyzing the impact of intentional and unintentional electromagnetic interference (EMI), and determining probable saturation conditions in spectrum usage and satellite orbital positions for space-related programs. An extensive Rand report[1] describes the procedures in detail.

The Air Force Space Division is planning to establish a continuing project to implement applicable recommendations and analysis capabilities documented in this paper and in the associated Rand report. The Advanced Space Communications Program Office (SD/YKX) will continue to be the office of primary responsibility at Space Division for the project. The YKX office will be supported by the Frequency Management Branch of the Directorate of Communications Electronics (SD/DC) for frequency management issues. The DC office will also act as the point of contact for the ECAC data base described in this report. The Deputy for Mission Integration (SD/YO) will provide support on operational issues (SD Reg. 55-1). The role of the Air Force Space Command in this project and in spacecraft orbital position management is being formulated. Copies of the report may be obtained from The Rand Corporation and from the Defense Technical Information Center (DTIC), Building 5, Cameron Station, Alexandria, Virginia 22314, Ph. #202-274-7633 (AUTOVON 284-7633).

The objectives of this project and the capabilities to meet those objectives requires a set of analytical procedures, computer programs to implement these procedures, and a data base to provide inputs to the programs. Such procedures, programs, and data bases have been developed at many organizations during recent years, and are listed in this paper. Investigations on nongeostationary orbits originated at Rand are discussed in a separate paper in this session. The referenced Rand report is principally devoted to an exposition of existing and planned techniques to investigate electromagnetic interference in space systems. The descriptions are planned to provide a comprehension of the structure and problem-solving capabilities of the analyses and programs. Much of the subject matter was initially furnished to Rand by persons from the companies or agencies where the analyses and codes were developed. The material was then modified by the Rand authors to bring all presentations to approximately the same level of complexity. This report may be viewed as a compendium, on an engineering or user's level, of the techniques for evaluating congestion problems in space systems. Since readers may desire copies of or additional information on particular programs, individuals for contact are indicated at the end of each subsection.

Because of the complexities of the spectral and orbital congestion problems, numerous organizations have developed models and programs to treat them. Often these models are of comparable scope and capability, and the prospective user should be aware of the existence of this multiplicity of programs and choose the one (perhaps several) which best suits his particular problem. Hence, we have included in the report descriptions of all of the programs for which we have received data, and have not indicated a selection between competing models. In the initial implementation phase of this program, choice among particular analysis codes and computer programs described herein should be the responsibility of the analyst who is investigating a specific problem. As this process develops, preferences among models should emerge based on utilization.

Orbital congestion problems, involving position allocation, nuclear collateral damage, avoidance of collision with debris or other satellites, and satellite repositioning, must be solved directly if space systems are to avoid catastrophic failures. These debris and collision avoidance issues are being treated by other projects. Extensive references are presented in the introduction to the Rand report, but the subject is not treated further in the text.

However, satellite repositioning may lead to spectral congestion problems if signals from the repositioned satellites interfere with signals from other satellites. These orbital-inducing-spectral congestion situations should be treated by the procedures described in this paper.

II. ANALYSIS PROCESS

The space systems spectral/orbital congestion analysis process has been divided into seven functional categories:

1. Regulations and procedures for radio frequency management
2. Cull and coordination
3. Cosite analysis
4. Intrasystem electromagnetic compatibility (EMC) analysis
5. Intersystem EMC analysis
6. EM vulnerability analysis
7. Multipurpose treatments

The separation into functional categories is basically geographic. Interference may be between parts of the same equipment complex (intrasystem), equipments at the same location (cosite), equipments at different sites (cull and coordination), via satellite links (intersystem), on complete networks (vulnerability), or several of these (multipurpose).

These categories separate the general scenario into specific areas which are appropriate for description of particular tasks. In addition, an extensive Space Systems Data Base is being established at the DoD Electromagnetic Compatibility Analysis Center (ECAC) in Annapolis, Maryland, to provide support for the investigation of the congestion problems. The proposed Space Systems Data Base, SSDB, will contain electromagnetic and operational characteristics of currently active and projected U.S. and international space systems. Information on both the space segments and related earth segments will be included. The SSDB will be structured to provide an automated file for quick access, culling, and printouts, and expanded information as available in documents, reports, and measured data. The file will include time-related information on deployed systems; currently active or in standby orbits; approved-for-launch systems with scheduled dates; firm and funded development programs; and future development plans with predicted schedules. ECAC maintains additional data bases necessary for EMC analysis to support DoD components and possible impact on space systems. A separate paper on ECAC Data Bases is included in this session.

The analysis of a complete system may be quite complex and several of the above categories may be involved. Some of the calculations may be conducted in parallel, and system or equipment design changes may force repetition of parts of the signal interference study. The title and brief definitions of each of the categories are given below.

The analysis codes and computer programs are described under each respective category in the Rand report. A standard format was used to describe the purpose, source, code operations and capabilities, software, and computer type for each of the programs. The Analysis Codes and Computer Programs and developing agencies are listed in Table 1.

Table 1

SPACE SYSTEMS ANALYSIS CODES AND COMPUTER PROGRAMS

1. Cull and Coordination Models:	
o Space and earth segments	ECAC
o ITU Radio Regulation Appendix 28, 29 Automation	ECAC, NTIA
o Ground mobile satellite terminals	ECAC
2. Co-Site Analysis: Earth, Mobile, Space Segments	ECAC
3. Intrasystem EMC Analysis:	
o Air Force Intrasystem Analysis Program (IAP)	RADC
Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP)	McDonnell Aircraft Co., RADC
General Electromagnetic Analysis Complex Systems (GEMACS)	BDM, RADC
Nonlinear Circuit Analysis (NCAP)	RADC
Wire Coupling Analysis	Kentucky Univ., RADC
o Intermodulation Analysis Program (IMOD IV)	Lockheed
4. Intersystem EMC Analysis:	
o Communications Satellites Interference Model	NTIA, Rand
o Adjacent Channel Interference Model	FCC
o Geostationary Orbit: Spectrum Orbit Utilization Program (SOUP)	ORI, NASA/LeRC
o Co-Channel Interference Analysis for Generalized Satellite Orbits	MITRE
o Interference Analysis for Non-Geostationary Satellites	Rand
o Air Force Satellite Control Program, Milestone 4	Data Dynamics, AFSCF
o Satellite Coverage, Simulation, Network Evaluation Programs	CSC, DCA
o Deep Space RFI Prediction Program (DSIP-II)	JPL
5. Electromagnetic Vulnerability Analysis:	
o MILSATCOM Vulnerability Analysis (MVAM)	Bell-TEXTRON, ESC
o Dynamic Multiple Message Simulator (SIMSTAR/DMMS)	IRT-AF/SA
o Propagation Network Analysis Code (PNAC)	CSC, AFWL
6. Multi-Purpose:	
o EMC Frequency Analysis (EMCFA)	Martin Marietta
o Specification and EMC Analysis Program (SEMCAP)	TRW
o Analysis Capabilities at ECAC	ECAC

1. Regulations and Procedures for Radio Frequency Management

The project was directed to comply with technical criteria, rules and regulations, and coordination procedures established by the international and national radio frequency management agencies. A section in the report provides a review of the organization and functions of the International, National, and DoD agencies.

2. Cull and Coordination

Cull models are procedures for excluding clearly non-interfering signals from extensive investigation of interference. Coordination models pertain to the coordination of frequency assignments among potentially interfering systems.

These programs deal with coordination of frequency assignments where signal paths may overlap international boundaries and areas within which interference is possible, and the programs have been developed to automate these calculations. The coordination may be between earth stations associated with satellite systems and stations involving terrestrial services, or between earth stations associated with different satellite systems, and there is a special set of coordination calculations involving ground mobile satellite terminals.

3. Cosite Analysis

This category is concerned with interference between independent systems located in the same small geographic area. A number of automated models calculate the linear and nonlinear couplings.

4. Intrasystem Electromagnetic Compatibility Analysis

This category treats compatibility within a system consisting of electrically interconnected equipments and/or equipments in proximity, such as those within a single aircraft, spacecraft, or ground station. These programs calculate interference in wire-coupled, antenna-coupled systems, nonlinear circuit transfer functions, and multiconductor transmission line interference.

5. Intersystem EMC Analysis

This category involves compatibility between systems that operate remotely and are coupled by antennas. The interference to be treated may be between satellites, ground terminals, and extraneous signals.

A separate paper is included in this session on the Spectrum Orbit Utilization Program (SOUP). This program was designed to compute interference among a large number of communication links, operating at the same or overlapping frequencies, between earth stations at specified locations through satellites in specified geostationary orbit positions.

6. Electromagnetic Vulnerability Analysis

This category pertains to the stressing of networks rather than individual equipments. The stress may be jamming, physical attack, or failure due to natural causes. Computer programs calculate message statistics such as failure of completion, queueing and preemption, and link and network error rates. Particular applications include military satellite communications networks and command, control, and warning networks.

A separate paper is included in this session on Propagation Network Analysis Code (PNAC) which is a tool for evaluation of satellite communication systems in nuclear disturbed and jamming environments.

An additional paper describes the MILSATCOM Vulnerability Analysis Model (MVAM), which is an analysis tool for design, development, and operation of MILSTAR satellite systems in electronic warfare environments.

7. Multipurpose Treatments

This category involves programs that can calculate interference of intra-, cosite-, and inter-system types.

III. APPLICATION

The tree diagram (Fig. 1) depicts the process to be used to investigate spectral or orbital problems that may arise when a new space system is developed or deployed by the Air Force Space Division. Similar procedures could be employed by other space-related organizations. The Air Force OPR would provide for management of the project and maintenance of a continuing analysis capability for use by the space-related System Program Offices (SPO) and SPO contractors of the Air Force Product Divisions. The SPO would provide access to the data base at ECAC, the analysis codes and computer programs, and analytic support by the respective SPO contractors. The Aerospace Corporation would assist the SPOs of the Air Force Space Division in monitoring contractor performance. The project contractor, in collaboration with the System Program Office, would determine which category or group of categories of analysis and programs are appropriate

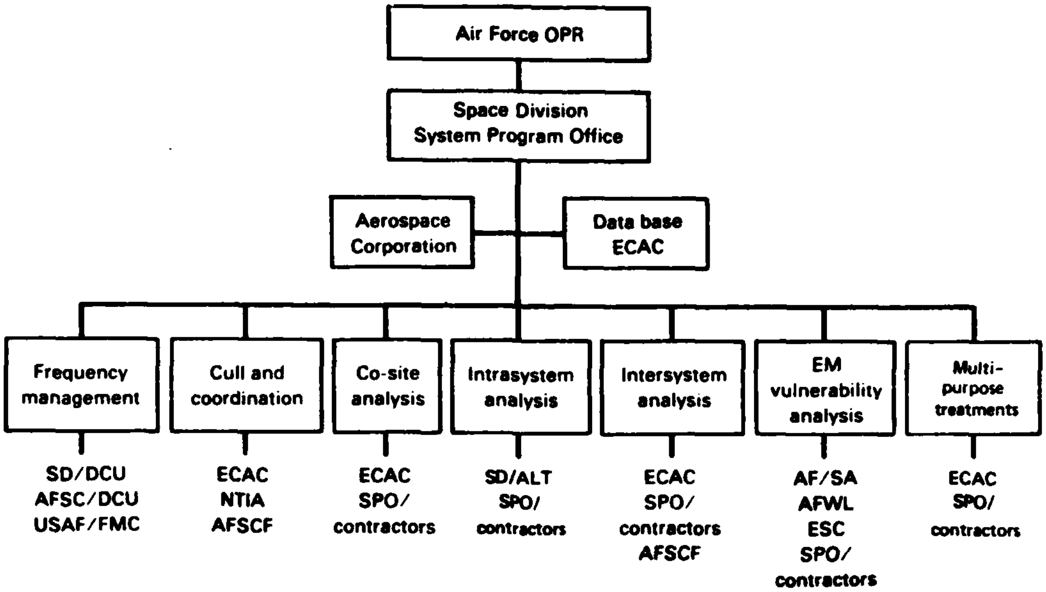

Fig. 1 -- Space Systems Spectral/Orbital Congestion Analysis Process

to investigate the potential spectral and orbital problems. When the category is selected, the project personnel arrange required support with the agencies or contractors indicated at the bottom of Fig. 1.

This process will require revising Air Force contract regulations and standards to include references to the Space Systems Data Base, analysis codes, and computer programs and procedures for their use. The following Air Force documents should be revised to include references and instructions for the use of this project.

SD Regulation 55-1, Satellite Position Management, 15 September 1983 (OPR: SD/YO)

AF Regulation 55-XY, Operations Spacecraft Orbital Position Management, Draft 10 March 1982 (OPR: AF/XOSO)

AF Regulation 100-31, Communications-Electronics, Frequency Management and Electromagnetic Compatibility, 23 July 1980, AFSC Supplement, 22 June 1981 (OPR: AF/SITI)

MIL-STD-1541 (USAF) Military Standard, Electromagnetic Compatibility Requirements for Space System, 15 October 1973, Proposed MIL-STD-1541A (USAF), Draft 15 August 1982 (OPR: SD/ALTI)

Air Force Regulation 80-23, Research and Development, The Air Force Electromagnetic Compatibility Program, 29 March 1982 (OPR: AF/RDPT), Space Division (AFSC) Supplement AFR 80-23, Draft 19 April 1983 (OPR: AF/ALTI)

References

1. R-3046-AF, "Techniques for the Analysis of Spectral and Orbital Congestion in Space Systems," by A. L. Hiebert and W. Sollfrey, March 1984, The Rand Corporation, 1700 Main Street, Santa Monica, California 90406. (Additional references are listed in the Rand Report.)

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